Lactose-Modified Milk and Whey

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□ USE OF LACTASE (β-galactosidase) to hydrolyze lactose, the major carbohydrate of milk, into its constituent monosaccharides glucose and galactose prior to product manufacture has received considerable attention during the past five years.

Studies in recent years have demonstrated a pattern of milk intolerance in non-Caucasian children and adults which has been attributed to low levels of intestinal lactase (Rosensweig, 1969; Paige et al., 1971). It has been estimated that approximately 70% of the world's adult population is lactose intolerant (Bayless et al., 1971). In the United States, about 40% of the black population show some symptoms of lactose intolerance by the age of ten years (Paige et al., 1975); in some developing countries the pattern of lactose intolerance can be much higher (Paige et al., 1972). In addition to the gastrointestinal discomfort brought about by milk ingestion by these individuals, a general impairment in the normal digestive process has also been observed. These findings have serious implications for nutrition rehabilitation programs based on milk products, as Paige et al., (1972) have pointed out.

COMMERCIAL PROCESSES

Although the potential for enzymatic modification of lactose in dairy products has been recognized since the early 1950s, it was not until the development of commercial processes for isolation of the enzyme from microbial sources that large-scale preparation of low-lactose dairy products became possible.

The two enzymes that have proven amenable to commercial production are isolated from the yeast *Saccharomyces lactis (S. lactis)* and the fungus *Aspergillis niger (A. niger)*. These lactases differ widely in their properties, particularly in pH optima. Lactase from *S. lactis* has a pH optimum of 6.8-7.0, a pH stability of 6.0-8.5 and a temperature optimum of 35°C; although suitable for treating milk (pH 6.6) and sweet whey (pH 6.2), the lack of stability below pH 6.0 precludes its use in treating acid whey (pH 4.5). *A. niger* lactase, with a pH optimum of 4.0-4.5, good pH stability (pH 3.0-7.0) and a temperature optimum of 55°C is suitable for the lactose modification of acid whey (Woychik and Holsinger, 1977).

Important considerations in the development of any large-scale enzymatic manufacturing process for lactose hydrolysis are the purity, activity, and cost of the lactases. Although the simplest method of achieving lactose hydrolysis is to add the soluble enzyme directly to the milk or whey, batch operations of this nature are expensive as the enzyme is not recoverable for further use.

Immobilized enzyme technology has been evaluated with lactases in attempts to improve the economics of lactose hydrolysis (Coughlin, 1977; Pastore et al., 1974; Wierzbicki et al., 1974; Woychik and Wondolowski, 1973). A discussion of the physical and chemical methods available for the immobilization of lactases is beyond the scope of this paper but has been recently reviewed by Wondolowski (1976). While an attempt has been made to develop a satisfactory immobilized system with *S. lactis* lactase, its lack of stability following immobilization has limited its usefulness (Woychik et al., 1974). In contrast, *A. niger* lactase has proven to be adaptable to use in immobilized form although some operating difficulties still exist (Hasselburger et al., 1974; Hustad et al., 1973; Olson and Stanley, 1973).

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TEST PRODUCTS

In order to evaluate the use of lactase in product manufacture, a series of dairy products were prepared from lactase-treated milk with 87-94% of the lactose present converted to monosaccharides (Guy et al., 1974). The enzyme used was isolated from the yeast *S. lactis* in the form of a colorless free flowing powder. Lactose hydrolysis was achieved in the batch process by incubating fresh pasteurized whole or skim milk preheated to 32°C with 300 ppm lactase for 2.5 hr with continuous agitation or by treating milk held in the silo at 4°C with 150 ppm for 16-18 hr (Thompson and Brower, 1976). After treatment in this manner, the milk could be used directly as a beverage or processed further into other products.

APPLICATIONS

Hydrolysis of the lactose in milk and whey results in several changes in its physical and chemical properties of interest to the dairy manufacturer. These changes include reduced lactose content, prevention of lactose crystallization, increased carbohydrate solubility, increased sweetness, and more readily fermentable sugars.

Applications are obvious, not only for producing milk and whey products with modified physical and functional properties but also for providing low-lactose dairy products for lactose intolerant or lactase deficient individuals.

MODIFIED MILK APPLICATIONS

Lactose-modified milk prepared in our pilot plant for beverage use was evaluated for its physical and organoleptic properties. Because both glucose and galactose are sweeter than lactose, some problems were encountered in defining the taste quality of the beverage product. Trained judges considered the marked sweetness of the milk to be a foreign flavor. An objective sweetness scale was subsequently developed to simplify reporting the changes brought about by lactase activity; the key feature was the fact that milk with 30, 60, or 90% of its lactose converted to monosaccharides was equivalent in sweetness to a control milk containing 0.3, 0.6, or 0.9% added sucrose (Guy et al., 1974).

Although the only change in flavor of lactase-treated milk detected by trained judges was increased sweetness, there was some question as to whether this flavor alteration would be acceptable to the consumer. In a limited test in our laboratory, fluid lactase-treated whole milk was judged by 15 to 20 persons using a nine-point hedonic scale (Peryam and Pilgrim, 1957). Hydrolyzing up to 60% of the lactose present in the milk resulted in little change in consumer acceptance. Although hydrolyzing 90% of the lactose produced a one-point decrease in acceptance score, we concluded that our results showed a positive acceptance of sweet milk because all scores obtained were above five, an acceptable rating according to the method used.

In a study carried out at Johns Hopkins University, Paige et al. (1975) reported that Negro adolescents, one of the target populations for low lactose milk, found milk with 90% of its lactose hydrolyzed quite acceptable to drink, even though 56% of the respondents judged it to be sweeter than an untreated control. More criticisms were voiced about the control; some respondants called the control more stale and others more sour than normal. The reported sweetness of the 90% lactose-hydrolyzed milk enhanced its desirability to these consumers.

• **Frozen concentrates.** Freshly prepared 3:1 concentrated milks show excellent flavor quality upon reconstitution and it would be desirable to find a method to store them without loss of quality. Such concentrates can be frozen but lactose crystallization, thickening, and coagulation occur shortly after storage begins.

Tumerman and his associates (1954) had previously shown that lactose hydrolysis led to the physical stability of frozen concentrates during storage. However, we found that hydrolysis of 90% of the lactose present increased storage stability in a frozen 3:1 concentrate by only one month over an untreated control (Guy et al., 1974; Holsinger and Roberts, 1976). Further examination of Tumerman's results showed that the samples had been heated above pasteurization requirements. When our lactase-hydrolyzed samples were post heated for 30 min at 71°C after canning, only a moderate rise in viscosity after 9 months of frozen storage was observed. There was no significant difference in flavor score of the reconstituted concentrate with 90% of its lactose hydrolyzed and an untreated fresh control with sucrose added (Guy et al., 1974; Holsinger and Roberts, 1976).

• **Dehydrated products.** Some problems were encountered in spray drying lactase-treated skim and whole milk concentrates. Because of the alteration of the milk sugar, the powder, particularly skim milk powder, had a tendency to stick to the hot metal surfaces of our spray dryer and to lump in the cone and star valve unless the powder was specially cooled with forced dry air as it left the cone. High yields of powder were obtained when a 42% total solids concentrate was injected with nitrogen gas and atomized through a 0.1 cm nozzle using an inlet temperature of 132°C. Powder left the cone at 68 to 70°C and was cooled to 35°C with forced air (Guy et al., 1974). Hedonic taste panel ratings of the reconstituted powder compared to fluid hydrolyzed milk showed that no quality loss occurred during drying.

• **Cultured products.** The manufacture of cheese from lactase-treated milk has been described (Thompson and Brower, 1976) but will be considered further here. Other cultured products besides cheese have been manufactured from lactase-treated milk. Yoghurt is enjoying a rapidly increasing popularity today, particularly the fruit flavored variety that comprises 90% of the market for this product (UDIA, 1973). Yoghurt has long been thought to contain low levels of lactose because of its utilization during the fermentation process. However, only 15-20% of the lactose is utilized during fermentation and the practice of fortifying yoghurt with nonfat dry milk results in appreciable amounts of added lactose. Lactose values of 3.3-5.7% have been reported in commercial yoghurts (Goodenough, 1975). Lactase treatment of milk prior to yoghurt manufacture resulted in accelerated acid development which may be due to the more rapid utilization of the total available carbohydrate when free glucose is present (O'Leary and Woychik, 1976). The manufacture of yoghurt from lactase-hydrolyzed milk also made plain yoghurt more acceptable to the consumer. Using a 9-point hedonic scale (Peryam and Pilgrim, 1957), consumers rated lactase-treated yoghurt 6.1 compared to 4.9 for the control. Apparently the acid flavor is reduced by lactose hydrolysis, and United States consumers generally prefer less acid yoghurts.

Low lactose cultured buttermilk also has been prepared from lactase-treated milk. Although coagulation time was reduced, the increased sweetness in hydrolyzed lactose buttermilk proved to be objectionable to consumers (Gyuricsek and Thompson, 1976).

Table 1—**RELATIVE SWEETNESS** *of sugars*[a]

Percent concentration to give equivalent sweetness			
Sucrose	Glucose	Fructose	Lactose
1	1.8	0.8	3.5
5	8.3	4.2	15.7
10	13.9	8.6	25.9

[a]Webb et. al., 1974.

WHEY APPLICATIONS

A spinoff of the manufacture of cheese from lactase-treated milk is that the whey produced contains hydrolyzed lactose. 36.4 billion pounds of whey containing approximately 2.4 billion pounds of solids were produced in the United States in 1976, only about half of which is being utilized (Crop Reporting Board, 1977). Whey, modified by lactase treatment, offers considerable potential for new avenues of utilization.

Whey, although containing small amounts of high quality protein, is essentially a crude solution of lactose. As shown in Table 1, the low sweetness level of lactose in solution relative to sucrose and other sweeteners does not permit its use as a sweetener, but lactose hydrolysis to glucose and galactose results in a marked increase in sweetness (Webb et al., 1974). In addition, the increase in solubility brought about by lactase treatment permits a noncrystallizing high solids whey concentrate to be prepared for use in ice cream and other foods.

• **Beverages.** The use of whey and its fractions in beverages has been studied extensively (Holsinger et al., 1974a). Whey has been used to make alcoholic and snack drinks, imitation milks, and liquid breakfasts, with protein levels ranging from less than 0.5% to more than 3.5%, depending on the type of beverage.

A major problem in using whey as a fermentation substrate for the manufacture of whey beer or whey wine has been that relatively few organisms can ferment lactose, *Kluyveromyces fragilis* being the most efficient (O'Leary et al., 1977a). In order to use a typical wine yeast, *Saccharomyces cerevisiae,* for the production of whey wine, Yang et al. (1975) added dextrose to the whey; the alcohol was produced by the fermentation of the added dextrose by the nonlactose fermenting organism, leaving the lactose intact.

The availability of lactase hydrolyzed cottage cheese whey prompted O'Leary et al. (1977a) to evaluate alcohol production in this medium, using *S. cerevisiae* and *K. fragilis* for comparison.

Complete fermentation of the sugar by *K. fragilis* required 120 hr at 30°C in lactase hydrolyzed whey compared to 72 hr in the control. This was due to a diauxic fermentation pattern in the lactase hydrolyzed whey with the glucose being fermented before galactose. Although *S. cerevisiae* produced alcohol from glucose more rapidly than *K. fragilis,* galactose was fermented only when *S. cerevisiae* was pregrown on galactose.

Because the presence of protein generally causes problems with clarity in the manufacture of any alcoholic beverage, O'Leary et al. (1977b) also investigated alcohol production in lactase hydrolyzed acid whey permeates prepared by ultrafiltration. With *S. cerevisiae,* alcohol yields as high as 6.5% were obtained in lactase hydrolyzed permeates condensed to 30-35% total solids prior to inoculation. The maximum alcohol yield obtained with *K. fragilis* was 4.5% at 20% total solids in the lastase hydrolyzed permeate and 3.7% at 10% total solids in the control permeate. Although *S. cerevisiae* efficiently converted the glucose present to alcohol, the galactose, comprising about half of the available carbohydrate in the lactase hydrolyzed permeate, was not utilized at all. Even though the alcohol yield was higher, the process was wasteful in that a good proportion of the substrate was not utilized. Therefore, it was concluded that although prehydrolysis of lactose in wheys and whey permeates is advantageous in that microbial species unable to ferment lactose may be utilized, a commercially feasible process must consider diauxic problems and must have an efficient means of rapidly converting galactose to alcohol.

A lactase hydrolyzed whey permeate has also been used to develop a prototype snack-type soft drink, Lactofruit (Anonymous, 1977). A new enzymatic electrocatalysis process was developed to provide constant control of enzyme activity, an advantage in maintaining production and quality control. It is claimed that the drink has a flavor quite different from normal whey beverages but the difference was not defined.

When nonfat dry milk was in short supply in the early 1970's, USDA and the Agency for International Development developed a new milk replacer, whey-soy drink mix, for use in Food-For-Peace child feeding programs in developing countries (Holsinger et al., 1974b). The formulation, containing 41.3% sweet whey solids, yields a finished product containing about 50% carbohydrate, the bulk of which is lactose.

As the product was designed for preschool children, no problems with lactose intolerace were anticipated and none have been reported to date. Because it has been suggested that as much as 50% of the population can be lactase deficient by three years of age in developing countries where whey-soy drink mix is distributed (Paige et al., 1972), it seemed advisable to investigate lactose-modified whey-soy drink mix. Therefore, trial production runs were made with whey with 90% of its lactose hydrolyzed; no drying problems were encountered. After 6 months of storage at 25°C, the products containing the lactase hydrolyzed whey were preferred by consumers, primarily because of the noticeably sweeter taste conferred by the lactase treatment (Holsinger and Roberts, 1976).

• **Frozen desserts.** Ice cream and other frozen desserts represent a very large outlet for milk. From about 13 billion pounds of whole milk, 1,187,000 gallons of frozen dairy products were produced in 1976 (Crop Reporting Board, 1977).

Guy et al. (1974) evaluated the use of lactase-treated whey as an ingredient in ice cream. Because of the increased sweetness brought about by lactose hydrolysis, sucrose levels could be reduced by 10% when lactase-treated whey was added at 25% of the total serum solids of the ice cream, without altering acceptability of the ice cream. Lowenstein et al. (1975) pointed out that ice cream prepared from a formulation in which 20, 50, or 100% of the nonfat dry milk fraction was replaced with a 35% total solids concentrate made from enzymatically hydrolyzed whey consistently produced flavor scores equal to those of a control made with nonfat dry milk.

Another possibility for utilization of lactase-treated whey is in novelty water ices. Guy et al. (1966) showed that cottage cheese whey could be incorporated in water ices at a 2.3% solids level. This is advantageous in that the addition of acid whey permits the manufacture of a less acid water ice; the calcium and phosphate present in the whey are also present in the ice pop and could be beneficial in reducing dental cavities (Wagg et al., 1965). With only slight modification of the formulation, lactase hydrolyzed whey could also be used in water ices.

Sherbet formulation containing 5% whey solids have been developed (Whittier and Webb, 1950). With only minor formulation alterations, lactase hydrolyzed acid whey might also be a useful ingredient for sherbet manufacture.

• **Confections.** At the present time, whey is not permitted in chocolate because it is not an optional ingredient within the chocolate standards (Code of Federal Regulations, 1973). Webb (1966) described a variety of other confections in which whey was successfully used as an ingredient. Candy makers have used whey in caramels for many years (Alikonis, 1972).

Guy (1977) evaluated the use of lactase hydrolyzed whey and hydrolyzed-lactose syrups as humectants in caramels. Caramels made without humectant showed much more sugar crystallization and shrinkage than those containing hydrolyzed-lactose syrup or whey. After 6 months of storage at 40% R.H. and 23°C, the products containing hydrolyzed-lactose lost significantly less moisture than did the controls. The best sample was a caramel prepared with a hydrolyzed-lactose syrup.

Guy (1976) prepared the syrup by treating lactose with *S. lactis* lactase for 6 hr at 30°C, decolorizing with carbon, demineralizing with ion exchange resins, and condensing the resulting solution, containing 90% hydrolyzed lactose, to 60% total solids. Syrups prepared in this manner were as sweet as comparable concentrations of sucrose about 40% total solids. Sugar crystallization was minimized by heating to pasteurization temperatures and storing in sealed containers. Although a syrup of this type cannot compete with high fructose corn syrups, it should find a place in those food applications where humectancy and good mouthfeel with some sweetness is desirable.

CONCLUSIONS

Today, the dairy industry has technology available for the enzymatic conversion of lactose in milk and milk products. Because of increased sweetness, some products could find use in calorie reduced sweet foods. Low lactose products might also be used with confidence by lactase deficient individuals. Whey, with its ever increasing production, poses special problems in utilization; the application of lactase technology offers a new opportunity for innovative whey processing into more profitable outlets.

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